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Computerised corneal topography applications in RGP contact lens fitting

Contact lens fitting is one of the most natural applications of computerised corneal topography (CCT). This technology is now found in almost all corneal and refractive surgery practices, and it is rapidly becoming accepted as the gold standard used to measure the cornea in many contact lens practices.

Most often, the instruments used in clinical practice are placido-based CCT systems, which employ a series of illuminated annular rings projected onto the cornea. Using the corneal tear film as a mirror, the reflected image of the rings is captured by a digital video camera. The captured image is then subjected to an algorithm to detect and identify the position of the rings relative to the video keratographic axis. Some thin ring projection systems, such as the TMS-2 (Tomey Technology), Humphrey Atlas (Zeiss Humphrey Systems) and Keratron (Optikon 2000), use a peak luminance algorithm where the brightest portion (the centre of the ring) is identified as the border. Wide-ring projection systems such as the EyeSys 2000 (EyeSys/Premier) and CT 200 (Paradigm Dicon) use a border detection algorithm to detect both edges of each illuminated ring (**Figure 1**). Once the borders are detected, a proprietary algorithm is applied to the digital image, which "reconstructs" the corneal curvature.

Software advancements in CCT have been rapid. Just over five years ago, the "standard" and often only topographic map available on first generation corneal topographers was the axial display. Now at least five different algorithms and their resulting displays are available across at least 10 different placido image systems. In addition, available software upgrades now include various colour scaling options, serial imaging, difference map calculations, disease detection programs, refractive surgery simulations, and sophisticated contact lens fitting software modules.

In RGP fitting, although new software packages are helpful for quantitative contact lens parameter selection, some of the most important fitting information can be retrieved from viewing the standard map displays. A good understanding of the available topography maps is extremely beneficial when determining the qualitative contact lens design. While the many variations of curvature maps and scaling differences can initially confuse or overwhelm those new to corneal topography, a basic understanding of these options is crucial prior to initiating an RGP fit.

Curvature map options

Curvature map options vary in their application of a mathematical function to the raw data. The most common maps used for the contact lens practice are the tangential radius of curvature representation (also referred to as instantaneous, local or true maps) and the axial representation (also referred to as sagittal, colour or default maps). Quantitative differences between the two representations become greater for corneal points in the mid to far corneal periphery, which results in many clinically significant differences relevant to contact lens fitting.

The axial map is based on a spherically biased algorithm that closely mimics keratometry measurements. It was intended to simulate refractive power in the corneal "cap" or supposedly spherical portion of the cornea. Since RGP lenses are globally fitted to the cornea, these averaged "axial powers" will usually provide the best RGP lens curvature. The tangential representation produces "true" curvatures based on a standard definition of the local curvature at a given point along a curve.

More specific details of tangential maps:

- Tangential maps include extreme curvature values and therefore offer a more detailed view of localised corneal curvature. Therefore, tangential curvatures of a relatively flat area of a cornea will appear to be flatter than the respective axial value, and relatively steep areas will be imaged steeper on tangential maps compared to their axial counterparts (**Figure 2**).
- Tangential maps depict a more accurate corneal shape which are better correlated to slit lamp observations of corneal pathology and RGP fluorescein patterns. Therefore, they are useful in RGP optical zone (OZ) selection if the OZ is targeted to vaulting a chosen area of the cornea.
- Tangential maps provide more detail to detect irregular astigmatism prior to RGP lens fitting, to monitor for contact lens induced warpage, and to track disease progression.

Colour scale options

Any of the curvature maps can be viewed with one of several colour scaling options - an absolute scale (also called a standard scale), a normalised scale (also called a colour map or an autosize scale) and an adjustable scale (also called a customised scale). Although these scaling options have long been available, their potential benefits and drawbacks are frequently overlooked. An absolute scale always assigns the same colour to a given dioptric interval of corneal curvature and forces the data to fit within a pre-determined dioptric range (e.g. for Tomey Technology and Optikon 2000 Keratron, from 9D to 100D; for EyeSys/Premier, from 35D to 52D; for Zeiss Humphrey Systems, from 39D to 50D). Because the scales are consistent each time this map is employed, it allows a direct and rapid comparison between the colour maps of one eye to another, or of the same eye on two separate occasions. It therefore avoids confusion and allows visual familiarity for the user. For the RGP fitter, the advantage of viewing this map early in the RGP fitting process is that it allows quick visualisation of significant astigmatism, and quick insight into the curvature of any eye. For example, if your RGP fitting approach changes based on the amount of corneal astigmatism or an average

Figure 1 Thick ring placido system

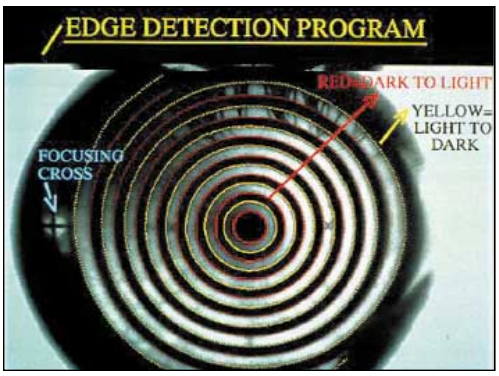
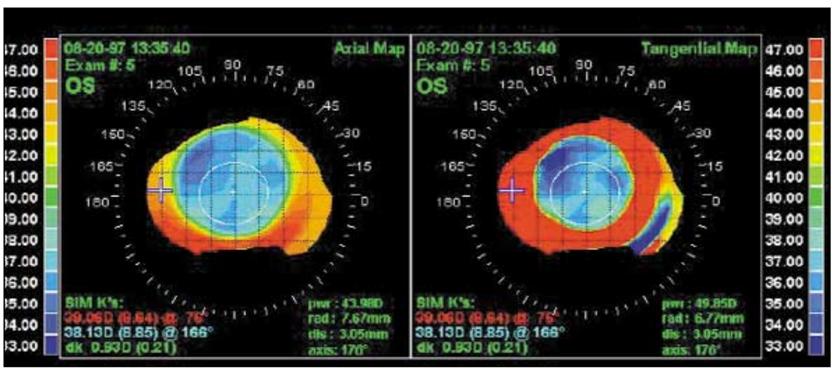


Figure 2 Comparison of axial and tangential maps of the same post surgical eye



corneal curvature, a mental reference of RGP design can begin at a glance of the absolute display.

Using only the absolute scale has certain disadvantages. In systems with a large range of curvatures, the scale uses a much larger interval than the normalised scale, which may mask clinically significant irregularities. Systems with smaller ranges may not have this disadvantage, but they may suffer from scale saturation. (The smaller range absolute scales are typically chosen by the manufacturer to simulate the range of a keratometer.) For example, if a cornea is unusually steep, such as in keratoconus, the entire map may appear as a "sea of red" with no interval definition because all curvatures are steeper than the 52D top interval of its scale (**Figure 3a**).

The normalised scale automatically adjusts and subdivides the map into multiple equal dioptric intervals based on the range of dioptric values found for that cornea. The colour intervals could vary in range and dioptric values between different eyes or occasions for a given eye. Therefore, normalised maps should not be visually compared at a glance without referring to the associated colour scale. A normalised display allows more detail because the colour intervals can be much smaller than the corresponding absolute maps (i.e. standard 0.50D steps in the EyeSys 2000, minimum step sizes of 0.40D in the TMS2, and 0.25D increments in the Humphrey Atlas Corneal Topography System). In fact, the normalised scale can produce a misleading map because it can take a normal cornea and exaggerate its shape to look abnormal with multiple colour changes from one region of the cornea to the next. However, it can also provide more definition in maps, which have saturated with the absolute scale (**Figure 3b**).

Elevation maps

Elevation maps display data differently from curvature maps although they use the same colour schemes. Most elevation maps depict relative height differences from a computer generated reference sphere, which best fits the measured corneal topography. Red or warmer colours now usually denote higher elevation values and blues or cooler colours denote areas of the cornea that are lower than the specified reference sphere. Once these elevation maps become familiar, they are very useful in predicting the appearance of what an RGP fluorescein pattern may look like on a given cornea without having to interpret curvature maps. The high (red) areas will always displace fluorescein and the low (blue) areas will always pool fluorescein. This is in contrast to curvature maps, where both steep (red) and flat (blue) areas may either displace or pool fluorescein depending on the corneal location. For example, steep curvatures will be high when centrally located, but will pool fluorescein (lower than the reference sphere) when located in the corneal periphery (**Figure 4**).

Serial images/ difference maps

Difference maps are simply mathematical subtractions of two selected maps and are specifically helpful in RGP lens fitting for monitoring for corneal warpage and post-fit corneal changes. Some manufacturers have a "healing trend" software module which may be optionally purchased and includes a five-map display of three serial topography maps and the respective two difference maps calculated from them.

Common corneal changes seen in a contact lens practice are mechanically induced PMMA and RGP changes, which can result in transient or permanent corneal warpage. Different forms of corneal distortion can be detected with CCT such as the shift from a prolate to an oblate shape, inferior corneal steepening, "smile" impression arcs, and variable irregular astigmatism.

Oblate shape

The normal cornea is a prolate shape, i.e. it is steeper in the centre and flattens aspherically in the periphery. Long-term flat fitting lenses can permanently shift the cornea to an oblate pattern by flattening the central cornea and secondarily, steepening the periphery. This type of warpage may not be detected with keratometry or manifest refraction if the astigmatism is regular and the patient remains correctable to 20/20. Only corneal topography can reveal the odd shape that may create difficulty in RGP fitting and problem solving.

Inferior corneal steepening

Long-term PMMA and low Dk RGP wear, and superiorly decentered rigid lenses can cause inferior corneal steeping which can simulate keratoconus. Corneal topography simplifies the detection of these corneal changes long before they are detected otherwise.

Smile patterns (impression arcs)

RGP induced arcuate corneal shape changes are most often located in the inferior third of the cornea and although they are common, it may implicate a sub-optimal fitting relationship that can be improved. In traditional RGP fitting, a flattened arcuate compression ring usually signifies unintended corneal moulding from the inferior edge of a superiorly decentered RGP. Just outside the lens edge, an arcuate zone of steepening appears, best viewed on a tangential map (**Figure 5**). If intermittent lens adhesion is detected (by removing the lens and looking for an epithelial indentation ring), an attempt should be made to flatten the posterior curves for improved corneal stability.

RGP CONTACT LENS FITTING

Pre-fitting analysis

The normal human cornea has been classically broken down into five topography shapes based on a normalised axial scale. A study by Bogan et al performed in 1990 on almost 400 normal eyes revealed that 22.6% of normal corneas are round, 20.8% have oval topographic patterns, 17.5% display a symmetric bow tie astigmatic pattern, 32.1% display an asymmetric bowtie and 7.1% display some form of an irregular pattern. The importance of knowing the peripheral corneal

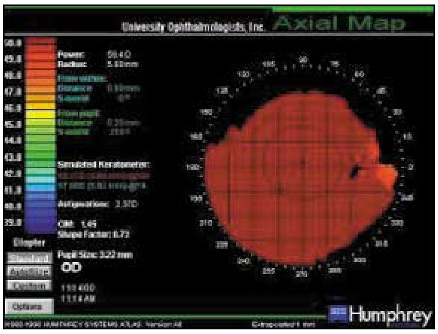


Figure 3a
Absolute colour scale saturates on a keratoconus eye

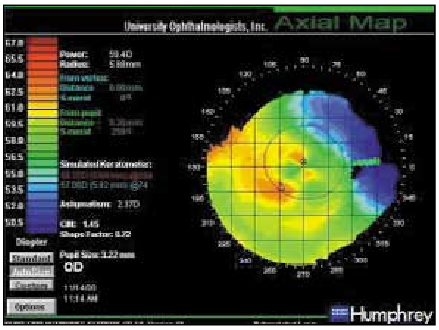


Figure 3b
Same eye in 3a viewed on a normalised colour scale

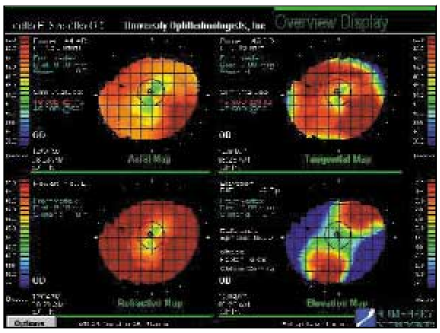


Figure 4
Post surgical cornea displayed as axial, tangential, refractive, and elevation maps. Note that the red curvature values in the corneal periphery are actually low elevation values which will pool fluorescein beneath an RGP lens

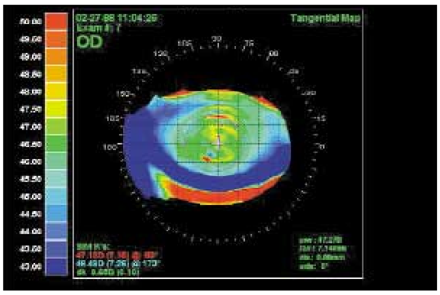


Figure 5
Smile arc pattern from a superiorly displaced RGP lens

Figure 6
Example of simulated fluorescein pattern

shape (in relation to the central cornea) becomes important during RGP lens fitting since RGP lenses have a tendency to migrate to the steepest hemi-meridian of a normal cornea. The pre-fitting analysis should consist of shape identification and proactive decision-making on the lens design and desired fitting relationship. The user should identify the steepest area of the cornea and assume the RGP lens will migrate along this “path of least resistance.” Once the steepest portion of the corneal surface has been identified, the default or preliminary contact lens design may change based on the location of the steep meridian. For example, if the steepest hemi-meridian is infero-temporal, assume the lens will decentre in the same position and the fitter may choose to design the lens flatter, larger, or with a minus-carrier lenticular edge to attempt to achieve a more superior riding fit or lid attachment.

CCT-based CL fitting modules

All CCT-based RGP fitting modules provide a simulated fluorescein pattern that demonstrates the predicted fitting relationship. Appropriate “fluorescence” is determined by the relative depth of the tear film under the contact lens and is helpful for patient education and rapid screening of various lens designs and parameters. It is important that this simulated fluorescein pattern accurately depicts the “on-eye” fluorescein pattern (**Figure 6**). However, parameters such as lid tension may influence the final lens position and may subsequently alter the actual on-eye fluorescein pattern and lens location. Although many topographers have the ability to manually adjust lens position across the corneal surface, most default to a geometrically centered lens position. Therefore, after any position or parameter change is initiated, the updated fluorescein pattern should be re-analysed. Currently, none predict blink-induced movement.

Spherical lenses

Most current generation contact lens modules incorporate peripheral corneal information during the initial base curve selection and they calculate suggested posterior lens curves based on a pre-selected tear layer thickness. Some systems use a form of a sagittal depth fitting technique, where the software can calculate a posterior lens curve beneath an optic zone until a desired tear layer clearance is achieved between the front surface of the cornea and the back surface of the contact lens. Most current generation programs utilise tear layer clearance and sagittal depth based on the captured corneal topography and/or corneal eccentricity. First generation programs utilised simulated keratometry readings only and simply applied manufacturers’ RGP fitting nomograms using corneal curvature and toricity data. However, without knowledge of either the corneal eccentricity or peripheral shape characteristics, this keratometric based fitting approach does not provide any more sophistication over the same nomograms a practitioner had available to them without using CCT.

Corneal eccentricity is a measure of peripheral corneal flattening. The specification of corneal eccentricity is borrowed from the mathematical description of an ellipse where zero represents a circle (or no flattening) and one represents maximum flattening in the periphery. The average cornea has an eccentricity of approximately e=0.55. The advantage of using corneal eccentricity in addition to central curvature in CCT based RGP fitting is illustrated in the following example.

Consider two corneas with the same central radius of curvature (e.g. 7.5mm) but with very different rates of peripheral flattening (eccentricity). With a standard keratometric-based fit, the same spherical base curve would be chosen for both eyes. If both eyes were fit “on-K”, an eye with rapid peripheral flattening (e.g. e=0.75) would have a steep lens-to-cornea fitting relationship because the sagittal depth of the spherical lens would be greater than that of the aspheric eye. Conversely, on an eye with minimal peripheral flattening (low eccentricity, e.g. e=0.25), a flatter lens-to-cornea relationship would occur because the corneal peripheral shape approaches that of a sphere and peripheral lens impingement would be minimised. Topography-based fitting nomograms based on corneal eccentricity can initially select appropriately different RGP base curves based on a pre-selected tear fitting relationship without the need to apply a variety of trial lenses.

The ultimate advantage of utilising corneal topography in RGP fitting is that it increases a practitioner’s efficiency. It does not necessarily make one a better contact lens fitter. The practitioner must still utilise a patient’s clinical data, which may be necessary to alter a suggested default lens during a “trial lens fitting” on the computer screen. The use of CCT-based fitting also eliminates the need for reusing and re-sterilising diagnostic trial lenses. Studies have shown that the success rates of corneal topography software programs are as high as 93% and match those of diagnostic fitting success of experienced RGP practitioners. Additionally, chair time can significantly decrease in those practices to less than 50% of the time required in a diagnostic lens fit, indicating increased efficiency without sacrificing accuracy for experienced RGP fitters or possibly an enhanced first time success rate for novice fitters. This is especially adaptable in settings that limit the time we may be able to spend with each patient. I personally use the various RGP contact lens fitting modules routinely when fitting non-surgical or non-diseased patients with RGP lenses as I find it provides similar accuracy to trial lens fitting with much less chair time and greater efficiency. Ideally, the flow from lens design to ordering from your laboratory should be smooth by electronic transmission of the data direct to your lab of choice or their lathe (already available on some systems). However, most users of these software modules usually print out a hard copy of the order for the patient’s chart and either call it in or fax it to the lab.

CCT-based CL modules - specialty RGP lenses

Many of the available contact lens modules also have the ability to create all types of complex contact lens designs in addition to simple spherical or aspheric lenses. Bitoric or front surface toric RGP lenses can be designed on most systems, and even reverse geometry lenses can be designed on systems such as Optikon/EyeQuip’s Keratron, Paradigm/Dicon’s CT 200, Humphrey Atlas, and Tomey Technology’s TMS-2 or TMS-3.

One of the most requested applications of CCT is toric lens fitting because many practitioners consider RGP back surface toric fitting a challenging process. Some contact lens fitting modules offer established bitoric fitting philosophies in their packages (e.g. Mandell-Moore bitoric fitting guide on Humphrey Atlas) or practitioners can customise a toric fitting program based on a pre-determined amount of corneal toricity that needs to be present before a toric lens will be suggested. The accuracy of such fitting programs has not been documented in the literature for specialty lenses, and I prefer to maintain fitting these patients with diagnostic RGP trial lenses until CCT based fitting success rates are determined.

Summary

Whether CCT is used qualitatively for RGP lens design selection or quantitatively in RGP parameter selection, it already plays a significant role in the RGP lens practice. Further advancements and testing on CCT-based RGP fitting modules and fluorescein simulations will continue to make CCT an invaluable tool for the RGP fitter.

About the author

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